ENVIRONMENT AND PRODUCTION TECHNOLOGY DIVISION MAY 2006

EPT Discussion Paper 152

An Exploration of the Potential Benefits of Integrated Pest Management Systems and the Use of Insect Resistant Potatoes to Control the Guatemalan Tuber Moth (*Tecia solanivora* Povolny*)* in Ventaquemada, Colombia

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ACKNOWLEDGMENTS

We gratefully acknowledge the support from Paola Nájar, Beatriz Franco-López, Jesús Gómez Benavides, Orlando Albarracín, José Moreno, Socorro Cerón, Edgar Villaneda and the UMATA of Ventaquemada for their invaluable data collection and analysis support. We would also like to express our gratitude to Patricia Zambrano and Joel Cohen (IFPRI), Dr. Marc Ghislain (CIP), Dr. Hector Quemada (Western Michigan University) and John Komen (Komen Consulting) for providing very valuable contributions and suggestions to earlier drafts of this paper. Finally, we are grateful for the support and openness of potato producers in Ventaquemada, Colombia; to them all the best in their efforts to decrease the damage that the Guatemalan Tuber Moth and other production constraints that Nature inflict on them everyday.

The authors wish to thank Dr. Svetlana Edmeades for her guidance and contributions during the review process of this Discussion Paper.

ABSTRACT

CORPOICA and IFPRI implemented a research project in Ventaquemada, Colombia. The project's goal was to asses the benefits of Integrated Pest Management (IPM) practices and the potential of Genetically Modified insect resistant (*Bt*) potatoes to manage damage caused by the Guatemalan Tuber Moth (*Tecia solanivora* Povolny*)*. The Guatemalan Tuber Moth is particularly destructive because field spraying on the adult stage is ineffective and there exists damage specificity to the tubers. Excessive pesticide sprays have resulted in resistance to several insecticides. Insect resistant (*Bt*) potatoes has been shown an effective means to control other members of the Tuber Moth complex. Thus a *Bt* potato may play a role in managing Tecia in Colombia. This is an *ex ante* study as there are no Bt potatoes currently under field conditions in Colombia.. To examine this issue, we conducted a survey in 2003 of 78 farmers in the region to estimate a baseline of traditionally and IPM managed systems. The first year survey was supplemented with focus groups to examine damage and production costs in 2003 and 2004. We also implemented activities such as field verification of IPM practices and damage, a Farmer Field School and other participatory methods. Our analysis uses methods such partial budgeting analysis, a production function input abatement expectations model, and an economic surplus model augmented by stochastic simulations. Results of the analysis presented here outlines estimated losses under field and storage conditions, likely range of benefits accrued by farmers in the region due to the potentia1 adoption of a portfolio of IPM management practices and *Bt* potatoes. Results from the survey conducted in 2003 show that producers in the area have endured significant field and storage losses within the previous 10 years, but were low in that particular year. Initial results where confirmed by results of focus groups in 2003 and 2004 which show very low field and storage damage. Sustained precipitation explains the observed low levels of damage by the Tuber Moth. Low levels of damage induced zero (or even negative) cost differences between conventional and IPM management. In contrast, using the proposed expectation model to estimate expected payoffs to IPM investments show that even with low levels of damage it still pays for producers to invest in IPM practices. The economic surplus estimates show that even considering variability of field and storage losses, as well as of other critical parameters, the use of Bt potatoes in Colombia creates a positive return to investment to Bt potato research, assuming that damage is present under field conditions. We finalize by discussing some of the institutional and strategic considerations for the potential use of Bt potatoes in the country.

Keywords: Potatoes, Integrated Pest Management, partial budget, economic surplus, stochastic simulation, Colombia

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1. INTRODUCTION

In Colombia, potatoes are produced mostly in smallholder farm systems characterized by high chemical input use and very intensive production per unit of land. Potatoes are cultivated in the highlands -the cold climate regions of the provinces (*Departamentos*) of Cundimarca, Boyacá and Nariño and a few others - and their production has been a driver of economic activity and growth, not only because of the income received by producers, but also through employment generation.

Colombian potato producers have been exposed to extensive capacity building and training activities, sponsored mainly by the public sector.[3] Among the activities are those undertaken during the implementation of agrarian reform programs,[4] capacity building efforts by the International Potato Center (CIP) in the mid-1990s, and the programs currently being sponsored by the Municipal Technical Assistance for Agriculture programs (referred to as UMATA, its Spanish acronym). Potato producers in Colombia have proven to be very receptive to new technologies (if appropriate) and they actively seek new alternatives to address their

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[3] The net benefit to recipient farmers will depend on the costs involved due to time and resource commitments and the expected benefits due to adoption of improved practices and behavioral changes.
[4] Agrarian reform in Colombia can be characterized by conflict, unequal distribution, failures, successes, and attempts to reform not only the existing situation but also the institutions created to address such critical problems. A fascinating discussion of the history of agrarian reform in Colombia can be found in Berry (2004) who discusses the initial agrarian reform that started with Law 200 of 1936, the Law 135 of 1961 that created the Instituto Colombiano de Reforma Agropecuaria(INCORA) up to current efforts and legislations. Programs and organizations created to support agrarian reform and rural development included the Instituto Colombiano Agropecuario (ICA), Corporación Colombiana de Investigacion Agropecuaria (CORPOICA), Cajas Agrarias (the Colombian bank for agriculture) and policies such as the Desarollo Rural Integrado (Integrated Rural Development – acronym in Spanish is DRI).

productivity constraints. Training activities introduced technological packages that included cultural and agronomic practices to manage specific pests and diseases.[5] These packages were disseminated in different potato producing region as discrete portfolios of Integrated Pest Management (IPM) practices focused on a productivity constraint (Cisneros and Gregory; 1994).

One of the most critical production constraints that potato producers have faced in Colombia is the Guatemalan Tuber Moth (*Tecia Solanivora* Povolny).[6] This pest was first found in Colombia in the mid 1980s and within years it disseminated in many potato producing areas posing a serious productivity constraint to potato production. Studies have documented production losses that reached 80 percent in some years (EPPO Bulletin 2005). During the periods of heavier losses many producers may not have covered their costs and in some cases may have been unable to repay pending credit obligations.

When the Guatemalan Tuber Moth (GTM) pest affected potato production in Colombia there was no technological response or management practice available to control the new pest. Producers experimented with high dosages and/or a large number of pesticide applications, without any significant success. Field spraying is ineffective when the moth is already in the adult stage (the strongest link in the life cycle). Sustained pesticide use may lead to resistance within insect populations. Moreover, biological control of the pest is not likely to work sufficiently well because of the excessive use of insecticides and the high specificity of damage to the tubers. Integrated pest management practices were not fully successful in managing the pest either, mostly due to the lack of commercial availability of key IPM inputs in Colombia. One significant effect of the damage caused by GTM was farmer migration of their production sites to

[5] For a complete list of practices included in the IPM package see Table 1.
[6] The potato tuber moth complex includes such lepidopteran insects as the common potato tuber moth -*Phthorimaea operculella* Zeller), the Andean PTM (*Symmetrischema tangolias*), and the Guatemalan PTM (*Tecia solanivora* Povolny) among others.

higher altitudes. The belief was at that point was that there would be less damage to the crop as GTM populations could not thrive at higher altitudes. One important collateral effect of potato production moving to higher altitudes was its damaging effect on cloudy forest and natural reserves (See Figure 1).

Figure 1 The Guatemalan Tuber Moth (GTM) larva, damage to the tuber, and the location of the study in the Republic of Colombia


Figure 1a. GTM larva


Figure 1c. Potato producing area in Ventaquemada Colombia

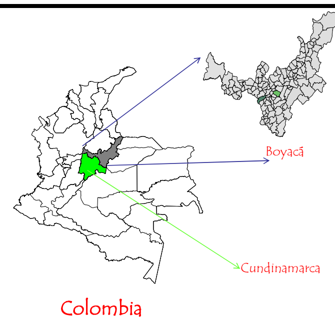

Figure 1e. Location of the study in the Republic of Colombia


Figure 1b. GTM damage to the tuber


Figure 1d. Potato production migration to high altitude areas "Paramos"


Figure 1f. Comercial potato storage facilities in Villa Pinzón, Colombia

Potatoes that have been genetically modified to express proteins that work as toxins from the soil bacteria *Bacillus thuringiensis (Bt)* have been shown to be effective means for controlling lepidopterans belonging to the potato tuber moth complex; and insects of other orders and families (Douches et al. 2004; Ghislain, Lagnaoui, and Walker 2003; Naimov, Dukiandjiev, and de Maagd 2003). There are several varieties of *Bt* potatoes developed by the public and private sectors that have provided adequate control of the tuber moth complex in other parts of the world, although none has been field tested or used in Colombia. The prospects that genetically modified *Bt* potatoes can play a role in solving the problem of GTM in Colombia are very promising.

In this paper we present the first results of an ongoing three year project co-sponsored by CORPOICA and IFPRI. The region selected to implement the study is the Municipality of Ventaquemada, Boyacá[7]. This is not only one of the most important potato producing regions in Colombia, but also one that has been exposed to a wide array of Integrated Pest Management (IPM) technology transfer programs and capacity building efforts in the past. The project includes gathering and analysis of potato production costs in the selected region, identification of factors affecting producer prices, and estimation of farmers' losses from infestations. We provide initial estimates of the economic cost and benefits of traditionally and IPM managed systems. We contrast these results with initial estimations of the potential value of the genetically modified (*Bt*) potato obtained through an economic surplus model augmented with risk considerations. The goal is to estimate the likely net benefits as a result of R&D investments in *Bt* potatoes in Colombia.[8]

2. SUBJECT MATTER, AREA DESCRIPTION, METHODS, AND TECHNIQUES

POTATO PRODUCTION IN BOYACÁ AND VENTAQUEMADA, COLOMBIA

According to statistics from the Colombian Ministry of Agriculture and Rural Development (DANE 2003), in 2002 there were over 163,000 hectares cultivated with potatoes in Colombia, with an estimated total annual production of 2.8 million tons of potatoes with and

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[7] See Figure 1 for a map showing geographical location of the study.

[8] We follow the convention of including all relevant prices, quantities and costs deemed as necessary to move the technology into the hands of the end-user; as described in the R&D impact assessment literature (Alston, Norton and Pardey; 1995). However, there are two potential target stakeholders for using this information: investors and/or implementers of R&D activities and technology users (farmers). There are some variations as to the type of questions and the methodological approaches necessary to address these questions of both target groups. More detail on this difference is provided in the methodology section.

average yield of 17 ton/ha. The provinces *(Departamentos*) of Cundinamarca, Boyacá, Nariño and Antioquia, account for 89 percent of the area planted with potatoes and 90 percent of its production. The remaining potato area is distributed in the Departments of Santander, Tolima, Caldas and the Cauca valley. Cundinamarca and Antioquia have the highest yields with an average of 21 ton/ha. In contrast, Boyacá has a significantly lower yield of roughly 16 ton/ha.

The 2002 Colombian National Agricultural census (DANE 2003) shows that the municipality of Ventaquemada with the largest cultivated area in Boyacá. The state of Boyacá has a total of 30,454 hectares in potato, with 10 percent of this area in Ventaquemada. The area planted to potatoes is distributed amongst 2,219 smallholder properties ("fincas"), with an average of 1.1 hectare per family. The 2002 census shows that of the total area planted in Boyacá 50 percent is cultivated with the variety "Parda Pastusa", 21 percent with Diacol Capiro (R-12), 12 percent with Tuquerreña, 5 percent with Única, remainder divided amongst other improved varieties.

Commercial production is predominately situated between 2,000 and 3,500 meters above sea level (*masl*). In contrast, smallholder production tends to located in a narrower range between 2,500 and 3,000 meters above sea level. There are two marginal production zones, limited mostly by diseases and pests: those with temperate climates between 1,500 and 2,000 *masl* and the cold climates in higher altitudes between 3,500 and 4,000 *masl*. Commercial potato production is located mostly in hillsides. The DANE survey estimates that only 10 percent of total area planted with potatoes can be considered leveled (potential for machine tillage) soils.

Potatoes in Colombia are planted in two semester long seasons with two harvest periods. The first harvest period runs from December to March. The second harvest is the largest and runs from June to September. The first harvest is characteristically unstable due to different climatic factors, in particular changes in precipitation. This causes seasonal variability and potato price volatility that is directed related to harvest and thus to precipitation.[9]

THE GUATEMALAN TUBER MOTH

The Guatemalan Tuber Moth has been reported as a pest of economic importance in Central America and in some countries of the Caribbean and South America. In the Andean region of South America, GTM has been reported as far as the extreme south of Ecuador, near the border with Peru. Larvae feed exclusively on potato tubers, both in the field and in storage. The GTM larvae damages tubers in storage by mining through the tuber and thus promoting the onset of bacterial and fungi infections. Damage to the tuber by GTM is similar to that of other tuber moths and is virtually undetectable until the fourth instar larvae burrows out of the tuber and exit holes are visible. Tuber quality is reduced significantly and heavily infested tubers cannot be used for human or animal consumption. Stocks can be fully destroyed or tubers rendered unfit for human consumption in less than 3 months, although in Colombia long term storage is not a common practice. In addition, storage damage in Colombia tends to be very low as producers cover tubers with powdered insecticide. Furthermore, producers and commercial buyers control the amount of damaged tubers and light in storage.[10]

Guatemalan Tuber Moth production damage was reported in the early 1970s. Hilje (1994) reports production damage of up to 95 percent in Central and South America. A report by Raman (1988) indicates that losses in 1972 in Costa Rica were approximately 20 to 40 percent of production in an area, corresponding to 2,000 hectares. Total damage was estimated by Raman to

[9] A seasonal stationarity index developed by Nájar (2004) showed a very unusual price behavior in 2002, when data collection for our study started. According to the estimated seasonal index, in 2002 there seemed to occur a departure in the relationship between precipitation and prices.

[10] Storage temperature affects the development of pest populations and subsequent damage to the potato tubers. More damage occurs as storage temperature increases, allowing faster pest population growth. However, there are very few instances where commercial buyers control temperature via refrigeration.

be approximately $900,000 per year. Raman also reports that the GTM has become so established in the environment that producers may apply 12-24 pesticide applications per season to control the pest.

In Colombia the pest was reported as a major economic constraint in Boyacá as early as 1988 (B. N. I. 1998). In 1994, Colombia attributed losses of 276,323 metric tons to the Guatemalan Tuber Moth (CABI 2000; Arias et al. 1996), which was more than nine percent of the national production for that year. Moreno et al. (1998) reports that in 1997 field and storage losses in Colombia sum approximately to US$70,000,000.

METHODOLOGY

Theoretical framework for the evaluation of Integrated Pest Management (IPM) practices

The economic surplus literature has been used to examine the impact of new technologies.[11] However, for the assessment of the economic impact of Integrated Pest Management (IPM) there are several methodological problems that are not easy to deal with conventional economic surplus models. The first problem is the way that smallholder producers adopt IPM practices. Usually smallholder producers do not adopt the whole portfolio of IPM practices suggested by research and extension services, rather parts of the IPM technological package. The partial adoption, adoption in stages or sequential adoption of IPM technological packages have been discussed in Feder and Umali (1993), having been suggested by Byerlee and de Polanco (1986). These authors found that in México smallholder farmers adopted in stages, beginning by those items they viewed as more profitable and less risky, then moving on to less profitable and riskier items within the IPM package. However, the sequential adoption has been

[11] Excellent compilations of economic surplus models and applications have been made by Maredia (2000) who contributed a manual of best practices, and the historical compilation by Pingali (2001).

disputed in other studies, where researchers tend to find that producers adopt IPM technologies in clusters (Rauniyar and Goode 1992).

Other examples of adoption of IPM in stages include Smith et al. (1987) who found that even though the whole IPM package was profitable, partial adoption of components of the package was still rational. Szmedra, et al. (1990) studied the interaction of IPM programs and irrigation technologies in a dynamic system that allowed the introduction of risk aversion processes. These authors found that under different patterns or risk aversion and climatic conditions, it was rational for producer to partially adopt items within the IPM portfolio. Pedrosa, et al. (1997, 1999) also found that the partial adoption of the IPM portfolio had significant effects in reducing of the number of applications of pesticides.

Partial or a step-wise adoption represents a problem for adoption studies of IPM portfolios. This is due to the fact that control of pests is obtained as a result of the complementarities of the different components within the IPM portfolio. It is not easy to define *a priori* the effect of partial or step-wise adoption. For the purposes of our study and the economic analysis to be done we identified nine practices that composed the original IPM portfolio suggested by the International Potato Center (CIP) in the region (Table 1).[12]

Table 1--The IPM Package to manage the Guatemala Tuber Moth (GTM) in Ventaquemada, Colombia

1) Good soil preparation
2) Deep planting
3) High row cultivation
4) Timing of harvest
5) Management of crop residues
6) Use of sexual pheromone traps
7) Cleaning and disinfection of storage site
8) Use of baculovirus as inoculant
9) Use of sexual pheromone traps

[12] One suggested practice in the IPM portfolio, the use of baculovirus, was used initially during CIP capacity building and training activities, but was not commercialized and this input was not available commercially in the region.

We defined a producer as an "adopter" of the IPM portfolio, when she utilizes more than 6 practices to control the GTM. This is a subjective assumption, but consistent with other studies such as Mauceri et al. (2005) in Ecuador, and Maumba and Swinton (2000) in Zimbabwe.

In Colombia, López and Barreto (2003) implemented an IPM Project, validated in four on-farm producer sites in Cundinamarca and Boyacá. Demonstrative plots of approximately 2,500 m^2 each showcased the use of certified seed, fertilization based upon soil analyses, use of raised beds and cultivation, use of pheromone traps and critical levels to guide pesticide applications, destruction of post-harvest residues, and appropriate harvest timing. Results from these demonstrative plots indicated that it was not necessary to apply any pesticide in three of the four plots, as the pest did not reach critical levels after the careful application of these cultural practices in conjunction with a regular precipitation regime. Samples taken before harvest showed that damage in these plots varied from 1.3 to 6 percent of total yield. However, after harvesting all the plots, total damage was lower than 2 percent.

Literature has cited many important variables to explain the adoption (and dis-adoption) of IPM portfolios and practices. In addition to risk, other explanatory variables such as distance from home to the production site (important as a determinant of the cost of monitoring) and farmer education and experience are important for explaining adoption of IPM practices. A significant explanatory variable of the dis-adoption of IPM is farmer's perception of the lack of effectiveness of any or some of the components of the IPM portfolio (Shaxson and Bentley 1992; Pedrosa 1999; and Baquero et al. 2003). One of the critical components in explaining adoption and the potential posterior dis-adoption is the availability of a private or public support system that supplies the necessary inputs to implement IPM programs. Inputs include pheromones, traps, baculovirus and other biological controls agents, etc. This was the case in Colombia, where producers could not access these inputs in a timely manner and thus where viewed by farmers as very effective but not applicable to their situation.

The second (well known) problem with the assessment of the economic impact of IPM practices is the estimation of the plant production function. Agricultural pests cause a reduction in productivity and thus pesticides (or IPM) seek to reduce the negative effect of pests to productivity. The maximum crop productivity is defined by the inter-relation between genotype and environment. This interaction is affected directly by the management practices. On the other hand, the damage caused by pests is determined by population sizes, phenological state -which in turn depends on climatic conditions- other sources of food, population mobility, and others. Note that there are several variables involved in this system and that these are interrelated with each other through feedback mechanisms and linkages, such that in the eyes of producers, pest attacks may seem purely random. In our survey, we found that the level of tuber moth attack was associated with rainfall as attacks were severe during the dry season and very low during the rainy season. This observation suggested that precipitation is an important stochastic factor in the producers' decision making process.

In Ventaquemada, traditional pest management is based on preventive methods and/or applications of pesticides based on a pre-determined and closely followed schedule. In our survey, potato producers applied –usually on a weekly schedule- chemicals to control fungal diseases (such as *Phytophtora infestans*) independently of whether the disease was present or not. Equally, other pests and diseases are treated with pesticides based on the stage of development of the plant following a strictly enforced schedule. In general, the effect of pesticides is dramatic as insect populations decrease almost immediately. In contrast, IPM practices seek to limit the number of applications according to critical population levels controlling insect population density.

An important component of IPM practices is thus prevention. The purpose of the preventive measures implemented by IPM practices is to initiate the production cycle with lower population levels of the Tuber Moth, and to reduce the possibility of re-infestations. An additional complication of the decision making process is that practices and activities seem to be correlated with potato price expectations. As described earlier, prices show a high correlation with plantings in November-December which coincides with the driest period in the season. In essence, the interaction between precipitation and pest populations imply higher risk with drought and attack by the tuber moth, but with consequent higher prices.

To estimate the expected net value of preventive measures we use the following simple decision making model based on Mumford and Norton (1984).We also utilize aspects of Oude Lansink and Carpentier (2001) and Brown, Lynch and Zilberman (2002) for the functional form of the production function of pest control. The potato production can be expressed as:

$$Q_t = Q_{max} * (1 - A(R, M))$$

where:

Q_t= Production in time t

Q_{max}= Maximum production capacity of the site being researched over time (plateau)

A= Guatemalan Tuber Moth attack

R = Precipitation

M = Preventive Measures

Attack is thus proposed to be a function of the level of precipitation and preventive measures. Precipitation is included in this model as a random variable. The first derivatives of A with respect to P_p and M are negative. Increases in precipitation and increased use of preventive measures decrease GTM attacks.

$$\frac{\delta A}{\delta R} < 0$$

$$\frac{\delta A}{\delta M} < 0$$

The expected value of investments E (B_n) in preventive measures can be estimated with the following formula:

$$E\,(B_n) = P\,(R) * Qt\,(R, M) - C(X_i) - C(M)$$

where:

P = Potato price

$C(X_i)$= Input costs

C(M)= Costs of preventive measures

According to this general model, relevant calculations include estimation of expected yield loss and the expected net benefit of control of the Guatemalan Tuber Moth. A distinct possibility of the expected net benefit calculation is that it may be rational to invest in preventive measures in the IPM portfolio even though there is the risk that high precipitation in particular production cycle reduces pest levels in the following production cycle, thus making investments redundant. This outcome may be important for our study, as field surveys have coincided with a crop period (2003-2004, 2004-2005) characterized by high precipitation. Under this circumstance, previous investments in IPM practices may not be compensated with posterior reductions in pesticide use, as there is a lower level of pest population growth due to rain. A short-term impact assessment based only on a particular year's results is not complete, as it would not consider the stochastic nature of precipitation, its effect on tuber moth populations and thus the observed level of damage. This would, be in fact, a static examination of a dynamic phenomena, and thus insufficient for decision making. To address this shortcoming we incorporate into the evaluation methodology information from previous periods, which include years with low and high infestation levels, particularly for the estimation of economic surplus models.

Ex ante estimation of the economic surplus resulting from the adoption of Bt potatoes

To assess the *ex ante* impact of the adoption of insect resistant potatoes in selected regions in Colombia we have to take into consideration distinct issues affecting potato production and its constraints, and the nature of the Guatemalan Tuber Moth. In particular there is a marked response of the GTM to environmental conditions, particularly precipitation. As discussed above, periods of precipitation during the developing period of the crop and the insect tend to decrease its incidence in the following growing season.

There are important questions with regard to the comparison of *ex ante* and *ex post* assessments of impact of insect resistance as *ex ante* approaches usually do not integrate the insurance characteristics of Bt insect resistance as a management tool. In essence even though in an *ex post* assessment producer may have lost due to a lower than expected infestation (or alternatively there was no pest pressure at all and the producer paid for a premium to use the technology), in an *ex ante* sense she would still be gaining an economic benefit[13].

An additional problem in Colombia is the determination of market prices. There are critical market imperfections that may affect prices and the distribution of benefits post adoption. The existing market structure is further complicated as producers consume their own production, but also produce for selling to the market. The traditional assumption of subsistence only smallholder farmers, who may sell production surpluses after satisfying household consumption needs, is very limited in Colombia.

Taking into consideration these problems and limitations, we present here a first approximation to the estimation of economic surplus of adopting insect resistant (*Bt)* potatoes in Ventaquemada and the department of Boyacá in Colombia. These estimates establish a lower boundary for benefits as we assume that a *Bt* potato technology will be able to eliminate the highest of the field and storage losses that occur even with the IPM or traditionally managed systems in our estimations of expected value of investment model above. The rationale behind our choice of having both the highest of either the traditional or IPM losses as a counterfactual is that we do not have access to data to construct a proper counterfactual. In an ideal comparison, we would contrast potato production systems managed traditionally, with IPM, with an insect resistant potato, and an insect resistant potato system integrated with IPM. As there are no *Bt*

[13] This line of reasoning is akin to the decision making process and the assessment of the value of purchasing life insurance.

potatoes varieties released into the environment in Colombia, we thus limit ourselves to the assumption of eliminating those losses from the traditional and IPM managed systems.

It is worthwhile to discuss two "empirical regularities" observed in other studies dealing with insect management using the *Bt* gene technology in other crops. With a decrease in pesticide used to control the target pest as a result of adoption of *Bt* technologies, secondary pests become important as they are no longer controlled (albeit indirectly) by the broad based insecticides used to control the primary target pest. Secondly, high enough pressure from the secondary target pest may require supplemental pesticide applications in spite of using the *Bt* crop. The impact of these empirical regularities may need to be qualified as management of secondary pests usually lends itself to IPM practices. In essence, we would foresee that biotechnology and IPM practices may be complementary rather than competing management options.

The small open economy surplus model

In this discussion paper we use a conventional small open economy surplus model (Alston, Norton and Pardey; 1995) to examine the likely socio-economic net benefits of the adoption of *Bt* potato technology in the Ventaquemada, Boyacá, Colombia. From the standpoint of the producer, standard economic surplus models do not explicitly consider production and investment risk considerations. We augmented the standard economic surplus model by including a more rigorous sensitivity analysis of key assumption parameters, in particular the supply elasticity assumption (Davis and Espinoza 1998; Zhao, et al. 2000; Falck Zepeda, Traxler and Nelson 2000), and of production parameters (Fisher, Masters and Sidibé; 2001). We also augmented the model to consider society's production and financial risks due to the distribution of field and storage losses likely to be faced by producers in the region as calculated in our expectations model above.

Target Stakeholders

As indicated in the introduction, we follow the convention in the R&D impact assessment literature of estimating changes in economic surplus induced by the adoption of a particular technology. Adoption of the specified technology induces a shift in the supply curve, which causes a change in the economic surplus. For the estimation of these changes, there is the need to include all the relevant costs (along with prices, quantities and structural assumptions embedded in the model) necessary to move the technology from the R&D phase to the hands of farmers for their adoption. Within this framework, socio-economic impact assessments have focused on estimating the (net) benefits to society[14].

There are two potential sets of target stakeholders who may use the estimations in this discussion paper to support their decision making process. First, investors and other financing actors and/or implementers of innovation activities and technology transfer organizations; second, producers who may adopt *Bt* potatoes and IPM as complementary technological approaches to manage losses due to GTM in Colombia. The decision making process and the determinants for both groups may be different and thus we describe them in more detail (For example, investors and R&D organizations may be interested in the minimum area necessary to obtain profits or to justify a breeding or testing program, or the (private) returns to private investments in agricultural R&D.)

When we describe the decision making process for funding actors and/or innovators of GM biotechnologies, we have to differentiate the process for two general groups implementing R&D. We have two distinct of R&D organizations: those organizations that will implement GM biotechnologies from discovery to innovation, and those that will adapt outputs from discovery

[14] Of course adoption of a technology can also lead to net costs to society. This situation would not be sustainable in the long term.

and R&D done elsewhere for use in-country. These general categories can be decomposed into distinct subsets and their permutations. In addition there are complications in terms of whether the analysis is *ex post* or *ex ante* or whether we are interested in private versus social returns to R&D investments.

The current situation in Colombia is that there are very few institutions developing GM technologies from inception to technology transfer[15]. Most of the ongoing research is based on genes developed elsewhere, that facilitate the developing or modifying transformation protocols that will enable the insertion of useful genes into Colombian germplasm. In this scenario, the innovator -who may be a public or private organization-, may either decide to transfer the technology to farmers or enter into strategic arrangements with private (or public) sector institutions to carry on such transfer. In this scenario the relevant costs include compliance with biosafety regulations, royalties to use the gene and germplasm technology, legal costs, registration, adaptive research; as well some of the post-release tech transfer costs that may be recoverable by the innovator itself through the technology fee or premium charged to farmers. However, most of the post-release costs are bound to be incurred by farmers. From the standpoint of investors or R&D institutions, the relevant factors are the price paid by farmers for the seed and the technology premium or fee, the availability of competing technologies, availability of production alternatives (such as conventional varieties with chemical control) and those costs not recoverable in the technology fee.

Public-private strategic partnerships introduce another set of complications for the economic analysis of GM biotechnologies. We will not pursue an analysis of this type of strategic partnerships in this paper, but can be accommodated into our methodology below. In this paper

[15] This situation is likely to change as the process of discovery of useful genes becomes internalized into general laboratory practice.

we explore the current situation of public/private sector institutions that have access to a gene construct, those willing to insert such gene into available germplasm, and those willing to know the feasibility of such intervention. In the case of producers, we provide an initial estimate of net benefits to farmers assuming that the R&D and tech transfer have been successful and price information is available.

Data sources

CORPOICA and IFPRI conducted a survey in 2002-2003 of 78 households to estimate the level of damage due to GTM in the field and in storage conditions[16]. Households were stratified in two groups with 39 households in each group. The first group included households that had received training or capacity building/strengthening activities in IPM practices. The second group included those that had not received any type of training or capacity building activity in the past. In this initial stage, information was collected on socio-economic characteristics, damage due to GTM, adoption/use of practices contained within the IPM portfolio, level of applied pesticides, knowledge about the insect itself, and some data on pesticide applications effects on human health[17]. The survey was conducted at the beginning of production cycle in 2003. We followed-up the initial data collected from farmers with personal visits to their households to verify adoption of IPM practices and by sampling potato yields and losses through field measurements.[18]

To complement the survey data we conducted community focus groups to measure damage and costs of production. Cost patterns (with IPM and conventional technologies)

[16] Budget considerations restricted the number of households surveyed. In addition, farmers in the area tend to resist providing household information due to security considerations and thus after the first survey we decided to approach farmers through different methods such as focus groups, a Farmer Field School and the implementation of a Farmer Field Day. These approaches built trust and confidence between farmers and our project.
[17] Due to the budget limitations we could not collect household specific agro-ecological data. This type of data is critical to derive significantly better determinants of technology adoption.
[18] A formal analysis of the determinants of IPM adoption will be pursued in a separate paper.

obtained from focus groups centered on a specific type of variety. Focus groups were conducted in 2003, 2004 and 2005, in this paper we report results from three focus groups conducted in 2003 and 2004. The first focus group, held in October 2003 focused on variety Parda Pastusa. The second focus group emphasized the industrial/variety type of potatoes. The third group focused on the variety Parda Pastusa. The later two focus groups were conducted in February, 2004. In addition to the focus groups, we surveyed 13 major commercial buyers of potatoes in the cities of Villapinzón and Tunja (both major centers for collection of potatoes) as well as 9 producers interviewed in situ, to examine the effect of the damage of the GTM on potato prices and on commercialization practices in the area.

3. DESCRIPTIVE STATISTICS AND PRODUCTION INFORMATION

POTATO VARIETIES AND PRODUCTION CHARACTERISTICS.

There are two types of potato varieties cultivated in the Ventaquemada region. The variety planted that covers a larger land area in the region is “Parda Pastusa.” Parda Pastusa is a variety developed and released in the 1950s by the “Instituto Colombiano de Agricultura (ICA).” This variety is utilized for direct consumption, seed and commercialization. When sold, Parda Pastusa potatoes are used mainly for consumption. The second type is a portfolio of improved varieties released mostly by Colombian research institutes–often referred to as industrial varieties- are mostly sold for processing. Among them are R-12, ICA-Huila, ICA-Unica, Marengo, Puracé, Tuquerreña, Flor Blanca and ICA-Morita varieties. The Parda Pastusa and the industrial varieties differ not only in terms of end use but also in productivity, price received by farmers and thus income per unit of land. Tables 2 and 3 present data for the Parda Pastusa and the industrial varieties portfolio.

Table 2-- Potato production and income generated per hectare by variety "Parda Pastusa", Ventaquemada, Boyacá, February 2004

Class	Tuber Size Large	Medium	Small	# of Cargas	Kg/ha	US$ / kg	Income (US$)
1. For seed		X		10	1,250	0.11	132
2. For self consumption		X		10	1,250	0.05	63
			X	10	1,250	0.02	26
3. For commercialization	X			100	12,500	0.11	1,316
		X		20	2,500	0.05	126
Totals				150	18,750		1,663

Notes:
Source: CORPOICA/IFPRI compilation of data from focus groups examining production cost in Ventaquemada, Colombia 2004
1 "Carga" equals 125 kg

Table 3 Potato production and income generated per hectare using industrial varieties, Ventaquemada, Boyacá, February 2004

Class	Tuber size Large	Medium	Small	# of Cargas	Kg /ha	US$ / kg	Income (US$)
1. For seed		X		8	1000	0.17	168
2. For self consumption		X		4	500	0.04	21
			X	4	500	0.02	11
3. For commercialization	X			140	17,500	0.08	1,326
		X		4	500	0.04	21
Totals				160	20,000		1,547

Notes:
Source: CORPOICA/IFPRI compilation of data from focus groups examining production costs in Ventaquemada, Colombia 2004
1 "Carga" equals 125 kg
Industrial varieties include such varieties as ICA-Huila, R-12, ICA-Unica, Marengo, Puracé, Tuquerreña, Flor Blanca and ICA-Morita.

Of those producers surveyed in the Ventaquemada area, most tend to sell a significant portion of their production, but they also save potatoes as seed and for own consumption. An important observation is that there are relatively few subsistence farmers in the region. Moreover, potato production is classified according to size. There are three size classifications: large ("gruesa"), medium ("pareja") and small ("riche"). The larger potato size obtains a higher prize and thus is typically sold. The medium size potato is used as seed for planting, family consumption and for sale. The small size is used for own consumption or for animal feed.

Farmers that cultivate Parda Pastusa receive a higher price than industrial varieties, although the quantity per hectare produced by industrial varieties is higher (20 tons versus 18.75 tons for Parda Pastusa). The price differential in 2004 between Parda Pastusa and industrial varieties was large enough to generate an income differential of US$ 116 per hectare in favor of Parda Pastusa in 2004.

POTATO PRICES AND TUBER DAMAGE

The price differential between Parda Pastusa and industrial varieties can also be seen in Table 4.

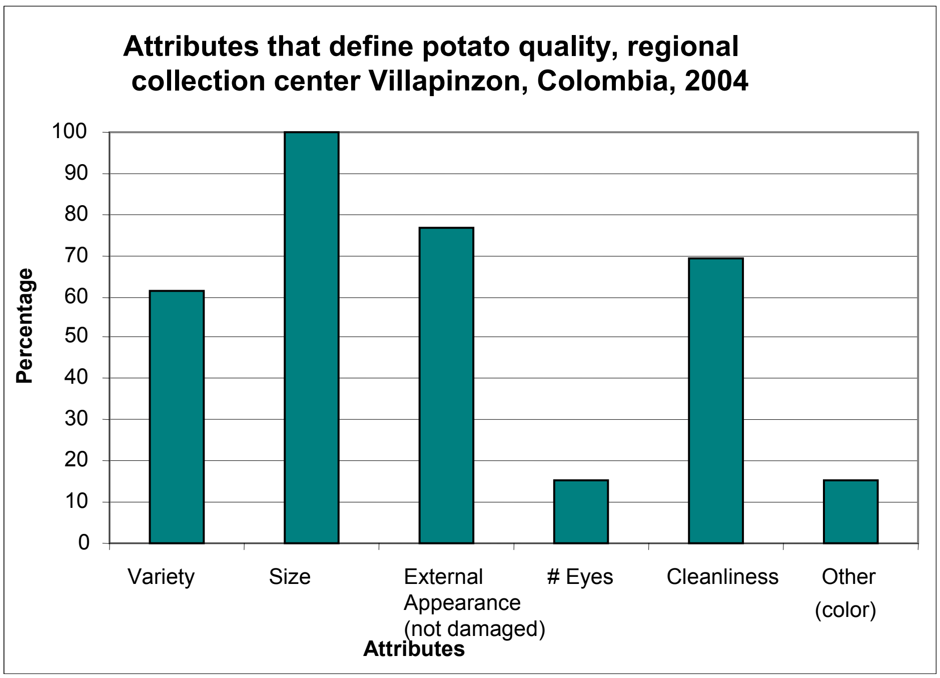
Table 4 Average potato prices based on type, variety and size from regional collection centers in Villapinzón and Tunja, Colombia, 2004

Type	Variety	Quality	Potato price (US$/kg)	Potato price if damaged (US$/kg)
Traditional	Pastusa	Large	0.11	0.04-0.06
		Medium	0.03	0.02
		Small	0.02	0.00
Industrial	R-12	Large	0.07	0.00
		Medium	0.03	0.00
		Small	0.01	0.00
	ICA-Huila	Large	0.08	0.05
		Medium	0.03	0.01
		Small	0.00	0

Source: CORPOICA/IFPRI survey of large buyers at the regional collection centers in Villapinzón and Tunja, Colombia, 2004

This table shows the results of a small questionnaire of 13 large commercial buyers in the nearest collection centers located in the nearby towns of Villapinzón and Tunja. These are the most important collection centers in the eastern region of Cundimarca and Boyacá. Both towns are regional collection sites for potatoes. As the table indicates large commercial buyers in these collection centers penalize producers if the tuber is damaged by paying less. Although tuber size and variety type are major determinants of potato prices, other quality characteristics are important such as damage, size of eyes, color and cleanliness (Figure 2).

Figure 2-- Attributes that define potato quality in the regional collection center of Villapinzón, Colombia, 2004



Source: Authors' estimations based on CORPOICA/IFPRI survey of commercial buyers and potato producers, 2004

The interactions between supply and demand are important determinants of potato prices. However, potato prices are determined largely at the wholesale market of Corabastos in Bogotá and others, and thus price determination is exogenous to the region (i.e. producers are price takers in Ventaquemada). There are several un-answered questions and speculation as to imperfections in potato markets and the ability of large commercial buyers and wholesalers to exercise market power in price determination in Colombia. If we compare the prices paid to farmers in our survey and a series of monthly average wholesale prices paid at the CORABASTOS market in Bogota, we see that there is a significant farm-to-wholesale spread.

We calculated a weighted average of prices paid to farmers based on size and production shares from our survey. The average price paid to farmers was 0.096 US$/kg. In the case of the average wholesale price paid at the CORABASTOS market, we used data from to estimate the average price for the months of January, February and March of 2004. The average price paid at the CORABASTOS market was 0.206 US$/kg. The farm-to-wholesale spread was 0.11 US$/kg, which represented a markup of 114 percent of price paid to farmers. The farm-to wholesale price spread is used to cover cost due to management, transportation and losses during transport, as well as, the risk associated with this process.

As information flows rapidly to all collection centers and other intermediaries through cellular phones, the ability to exercise market power may have decreased over time. In addition, the commercial buyers surveyed, although tied to the larger market of Corabastos, also sell in other important markets such as Tolima or the Atlantic coast. Thus, the assumption of using the price taker assumption within a small open economy may be closer to reality than compared to imperfect model assumptions. This is indeed a critical area to pursue future research within the potato production system.[19]

Our small buyer and *in situ* producer questionnaire indicates that both producers and large commercial buyers understand that potatoes with tuber moth damage are in principle not accepted at the collection centers. Purchasers usually examine 1 to 3 bags ("costales") randomly selected from the producers' truck. Potatoes with tuber moth damage are rejected, sometimes leading to the rejection of the whole shipment. Potato buyers recognize that it is nearly impossible to have only undamaged tubers in a given shipment and thus producers admit a very small margin of

[19] We envision that another area of future research is to develop models to explicitly include the dual consumption and production characteristics of the household model. This may not be as critical for Colombian producers in Ventaquemada as they are very profit oriented, but will be critical for the analysis in other areas of the Andes, where there are more subsistence farmers.

damaged tubers. Roughly, 89 percent of large buyers allow a small damage margin equal or less than 5 percent. If buyers receive a shipment with damaged potato tubers, they severely penalize producers by paying a lower price. Most of the time, the damaged potatoes are used for animal feed. As explained by large buyers, having any inventory with damage puts their whole inventory in danger of further damage.

In our survey we also asked the same set of producers about acceptability of a transgenic variety of potatoes. Roughly 85 percent did not know what a transgenic variety was, but 92 percent would be interested in selling a potato with the same quality characteristics as the ones currently marketed, particularly if these varieties were resistant to the attack of the tuber moth.[20]

POTATO PRODUCTION COSTS

Table 5 shows the 2004 costs of production of Parda Pastusa and industrial varieties produced using IPM and traditionally managed systems.

[20] A study by Buijs, *et al*. (2006) in Peru presented similar results to the findings of our study with regard to acceptability of a potato resistant to GTM damage.

Table 5 Production costs of Industrial and Parda Pastusa potato varieties under IPM and conventional systems for the management of Guatemalan Tuber Moth, Ventaquemada, Colombia, 2004.

	Production costs industrial varieties (US$/ha)				Production costs "Parda Pastusa" variety (US$/ha)			
	Traditional		IPM		Traditional		IPM	
Activity	Total	%	Total	%	Total	%	Total	%
Direct costs								
Labor								
1. Residue collection	0	0	47.4	1	0	0	47.4	1
2. Soil preparation	110.5	3	110.5	3	151.6	4	151.6	4
3. Planting	63.2	2	63.2	2	55.3	1	55.3	1
4. Pest and disease control	378.9	10	371.1	10	252.6	7	252.6	7
5. Crop management	157.9	4	173.7	5	173.7	5	173.7	5
6. Harvest	210.5	6	210.5	6	150.0	4	150.0	4
Subtotal Labor	921.1	25	976.3	26	783.2	21	830.5	22
7. Inputs								
7.1. Seed	210.5	6	210.5	6	131.6	4	131.6	3
7.2. Fertilizer/correctives	847.4	23	847.4	22	757.9	20	757.9	20
7.3. Pesticides	834.7	23	813.7	21	1271.1	34	1231.6	32
7.4. Packing material	247.4	7	247.4	7	213.2	6	213.2	6
7.4. Biological control	0.0	0	42.1	1	0.0	0	42.1	1
7.5. Etological control	0.0	0	33.7	1	0.0	0	33.7	1
8. Transportation	157.9	4	157.9	4	189.5	5	189.5	5
Subtotal Inputs	2297.9	62	2352.6	62	2563.2	68	2599.5	68
Subtotal Direct costs	3218.9	87	3328.9	88	3346.3	89	3430.0	89
Indirect costs								
9. Leasing costs	184.2	5	184.2	5	105.3	3	105.3	3
10. Administrative (6%)	193.1	5	196.9	5	200.8	5	205.8	5
11. Interest	90.5	2	92.7	2	101.0	3	102.4	3
Subtotal Indirect costs	467.9	13	473.8	12	407.0	11	413.5	11
TOTAL	3686.8	100	3802.7	100	3753.3	100	3843.5	100

Source: Source: CORPOICA/IFPRI compilation of data from focus groups examining production costs in Ventaquemada, Colombia 2004

The costs of production of both management systems are very similar during the period of the survey as producers reported low levels of GTM attack during the examined cultivation period. The total cost per hectare for industrial varieties under the traditional management system is US$3,686 whereas with the IPM managed system the cost increases to US$3,802. In contrast, the total cost per hectare for Parda Pastusa is US$3,753 for the traditional management system, versus US$3,843 for the IPM managed system.

As can be seen from Table 5, potato production is typically labor intensive. Labor constitutes 21-26 percent of total costs for both variety types and management systems. The largest share of labor corresponds to pest and disease control, crop management and harvest. The largest shares of total cost of production correspond of fertilized/correctives and pesticides.[21] Figures presented in table 5 show a small savings in pesticides for using the IPM management system, but also a small increase in the cost of labor in 2004.

4. RESULTS

RELATIVE VALUES OF IPM AND CONVENTIONAL MANAGEMENT SYSTEMS

To better understand the relative value of IPM and traditional management systems we conducted a series of partial budgeting exercises using results from cost of production focus groups in 2003 and 2004.

The partial budgeting exercise examining the profitability of the production periods that ended the second semester of 2003, shows a small positive net benefit using IPM practices to manage the Guatemalan Tuber Moth of US$ 41.2 per hectare (Table 6).

[21] Most of the pesticide expenses were used to control “gota” *(Phytophtora infestans*) a fungal disease.

Table 6--Partial budgeting analysis of profitability of the use of IPM in a production system with variety "Parda Pastusa" in Ventaquemada Colombia October 2003

Additional Costs		Cost savings	
Labor		Labor	
Residue collection	19.7	Insecticide applications to control GTM	59.2
Aporque	19.7		
Sub-total	39.5	*Sub-total*	59.2
Biological/etological inputs		Savings in chemicals	
Pherhormones	50.0	Insecticide (Chlorpyfifos)	82.9
Insecticide (Phoxim)	7.9		
Fungicide(Carboxamide)	6.6		
Sub-total	64.5	*Sub-total*	82.9
Indirect costs	8.8	Indirect costs	11.8
Total	112.7	Total	153.9
		Net benefit of using IPM =	41.2

Source: CORPOICA/IFPRI compilation of data based on cost of production focus groups Ventaquemada, Colombia 2004

In contrast, during the first semester of 2004, IPM adoption showed a loss of US$90.1 per hectare for Parda Pastusa and US$118.8 for the industrial varieties (Tables 7 and 8).

Table 7-- Partial budgeting analysis of profitability of the use of IPM in a production system with variety Parda Pastusa in Ventaquemada Colombia February 2004

Additional Costs		Cost savings	
Labor		Labor	
Residue collection (animal traction)	31.6	Insecticide applications to control GTM	**0.0**
Residue collection (Manual)	15.8		
Sub-total		*Sub-total*	0.0
Biological etological inputs		Savings in chemicals	
Pheromones	42.1	Insecticide (Chlorpyfifos)	**39.5**
Insect traps	6.3		
Insecticide (Phoxim)	6.3		
Fungicide(Carboxamide)	21.1		
Sub-total	75.79	*Sub-total*	39.5
Indirect costs	10.4	Indirect costs	3.9
Total	133.5	Total	43.5
		Net benefit of using IPM =	-90.1

Source: CORPOICA/IFPRI compilation of data based on cost of production focus groups Ventaquemada, Colombia 2004

Table 8--Partial budgeting analysis of profitability of the use of IPM management practices in a production system that utilizes industrial varieties in Ventaquemada Colombia February 2004

Additional Costs			Cost savings	
Labor			Labor	
Residue collection (animal traction)		31.6	Insecticide applications to control GTM	7.9
Residue collection (Manual)		15.8		
		15.8		
Sub-total		63.2	*Sub-total*	7.9
Biological/etological inputs			Savings in chemicals	
Pherhormones		42.1	Insecticide (Chlorpyfifos)	21.1
Insect traps		6.3		
Insecticide (Phoxim)		6.3		
Fungicide(Carboxamide)		21.1		
Sub-total		75.78	*Sub-total*	21.1
Indirect costs		11.3	Indirect costs	2.6
	Total	150.3	Total	31.5
			Net benefit of using IPM =	-118.76

Source: CORPOICA/IFPRI compilation of data based on cost of production focus groups Ventaquemada, Colombia 2004

The small difference between both types of varieties may be due to smaller level of savings in chemicals in industrial type potatoes. A similar pattern of losses to IPM managed systems as compared to traditional systems was also found in the second semester of 2004; results of this exercise are not presented here.

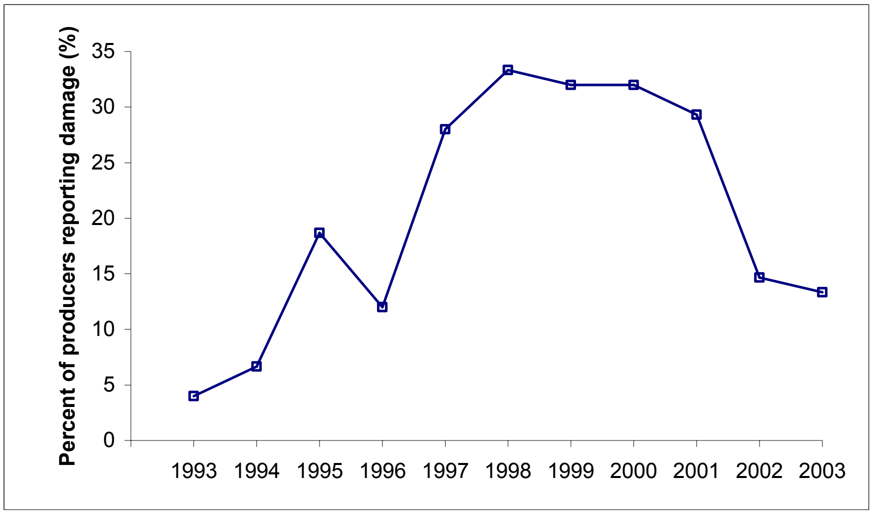
Does a loss as a result of a partial budgeting exercise indicate that it does not pay for producers in the Ventaquemada to use IPM? An answer will be provided in subsequent sections when the expectation of damage is introduced.   For now we can generalize that IPM managed systems imply additional higher costs of production in terms of residue collection and the materials required for biological and etological control, but this increment is so small that it probably will not be a major determinant of adoption of IPM practices. In the absence of the pest attack, profitability depends significantly on the reduction of conventional pesticides. Thus damage levels -both in the field and in storage- become critical for the evaluation of benefits to producers.

EXPECTED VALUE OF THE GUATEMALAN TUBER MOTH DAMAGE ON POTATO PRODUCTION

To verify damage that producers endured in the region we conducted additional focus groups in 2003 and 2004.[22] In these focus groups producers clearly reached the consensus that there were no significant differences between the tuber moth damage within the traditional and the integrated pest management system. In addition, field damage was less than 5 percent of total production. Because of the low damage reported in the focus groups we will make use of the results from our 2002-2003 original survey with producers stratified by reception of IPM training in the past. In the survey we included a series of questions to recover parts of the historical record of production losses. We asked producers to list the 3 years with highest levels of tuber moth attack in addition to corresponding yield and storage losses and to estimate the level of damage in those years. Recollection of previous (historical) events does have the disadvantage of relying on peoples' memories and thus these estimates may underestimate or overestimate yield losses. Experiences by the Colombian authors of this paper in the region seem to indicate that producers tend to overestimate the damage reported in previous surveys. Yet, we may be able to control partially for the memory bias effect as we asked for the three highest damage levels over time. Figure 3 shows the results of producer answers to the question of years with largest losses due to the tuber moth, and accounts for the percent of producers that indicated a year of reference. More than 25 percent of producers report heavy losses from 1997 to 2001. The incidence of the pest is lower in the last two years.

[22] We are finalizing the analysis of the 2005 focus. Preliminary assessment shows that in 2005, damage due to the GTM pest was also very low.

Figure 3--Percent of producers reporting heavy yield losses 1993-2003 in Ventaquemada, Colombia



Source: Authors' estimations based on CORPOICA/IFPRI survey

We refined our estimates by specifying average losses that producer endured, separating those producers that used traditional system and those that used the IPM system. To address the issue of the partial adoption of the IPM portfolio, we (subjectively) defined producers as "adopters" of the IPM portfolio as those that adopted 6 or more IPM practices of the total recommended portfolio (Table 9).

Table 9--Percent yield losses from the Guatemala tuber Moth under the traditional and IPM management systems, Ventaquemada, Boyacá, Colombia

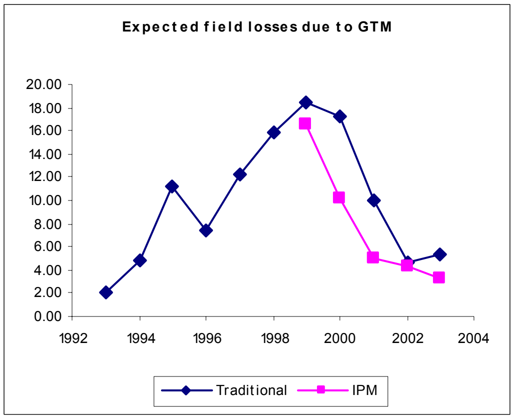
	Traditional Systems		IPM System		Difference	
Year	Yield Losses (%)	Storage Losses (%)	Yield Losses (%)	Storage Losses (%)	Yield Losses (%)	Storage Losses (%)
1993	51.7	56.7				
1994	73.0	46				
1995	59.6	57.9				
1996	61.1	77.8				
1997	43.8	51.4				
1998	47.7	41				
1999	57.5	42.5	51.6	5.9	5.9	-6.5
2000	54.0	29	31.8	22.2	22.2	7
2001	34.2	37.5	17	17.2	17.2	25.2
2002	31.4	25.7	29	2.4	2.4	13.2
2003	40.0	20	25	15	15	10.7
Average	50.4	44.1	30.9	12.5	12.5	9.9

Source: CORPOICA/IFPRI survey

Field losses averaged 50.4 percent for the traditional system, whereas the IPM system average was 30.9 percent. In contrast storage losses average was 44.1 and 12.5 percent for the traditional and the IPM systems respectively. Producers started adopting IPM practices in 1977. There is a clear reduction in yield losses caused by the attacks of the Tuber Moth under the IPM system. In average, the difference in yield and storage losses is 12.55 percent for yield in the field, and 9.92 percent in storage between the traditional and the IPM system.

Figure 4 shows results of the first step in the application of our model developed in section 2.3; to estimate the expected yield and storage losses.

Figure 4-- Expected field and storage losses due to the Guatemalan Tuber Moth in Ventaquemada, Boyacá.



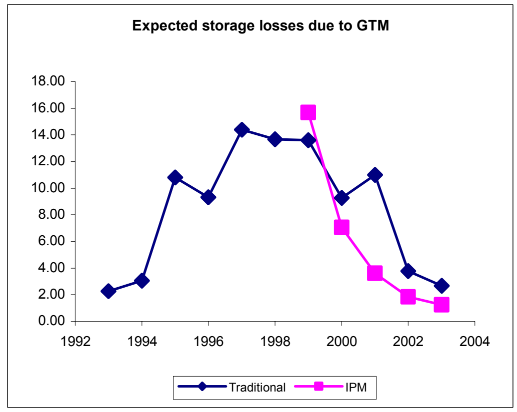


Figure 4a Figure 4b
Source: Authors' estimations based on CORPOICA/IFPRI field survey

To obtain expected losses we used the segregated responses of adopters/users of IPM and of the traditional production systems, not according to the IPM training efforts received in the past. The estimated expected losses are calculated as the percent loss (Table 9) multiplied by the probability of suffering an attack (Figure 3). On average, the expected yield losses in physical terms are 9.93 percent for the conventional system and 7.85 percent for IPM. In contrast, in storage expected yield losses are 8.53 percent for the conventional system and 5.88 percent for the IPM system.

To estimate the expected gross benefit of utilizing IPM versus traditional systems, we used average prices for year 2003-2004 for Parda Pastusa variety and other production data for this variety reported in the focus groups. We assumed that producers stored 2500 kg of potatoes, 1250kg for seed and 1250 kg for own consumption (Similar to data in Table 2). Results of this exercise, presented in Table 10, show that IPM represents an average saving in terms of field and storage losses avoided of US$129.2. Hence, this result shows that it is rational for producers to invest in IPM preventive measures even when no damage is reported for the tuber moth as the expected value of losses ($129.2) is higher than the cost of preventive measures.

Table 10--Gross value of yield and storage losses as a result of using IPM practices to control the Guatemalan Tuber Moth, Ventaquemada, Boyacá, Colombia

Year	Reduction yield losses (%)	Reduction in storage losses (%)	Value of reduction in yield losses (US$ current)	Value of reduction in storage losses (US$ current)	Total values (US$ current)
1999	1.9	15.7	60.1	66.2	126.3
2000	7.1	7	224.9	29.7	254.6
2001	5	3.6	159.3	15.2	174.5
2002	0.4	1.8	11.3	7.7	19.0
2003	2	1.2	63.4	5.3	68.6
Average	3.3	5.9	103.8	24.8	129.2

ECONOMIC SURPLUS ESTIMATES

Assumptions

All of the baseline assumptions of the model are included in Table 11. Based on these assumptions we calculated four distinct scenarios using the @Risk™ software. The @Risk™ software allows substituting single assumption values for a probability distribution.

Table 11 Baseline assumptions in Economic Surplus analysis

Variable	Assumption	Comment
Model	Small open economy	Model implies no consumer surplus
Estimated R&D + regulatory cost distribution	Triangular (US$600,000; 980,000; 2,000,000)	Most likely value is from estimates from data collected in studies in India and South Africa for a similar Bt potato. Includes cost of compliance with biosafety regulations and adaptive R&D for gene insertion.
Technology fee	No technology fee	No attempt is made to recuperate investments in R&D, biosafety compliance and post-release monitoring. Assumption used to calibrate model.
	US$20 and US$80 per hectare	Premium for use of the technology expressed as the range of technology fees charged for insect resistant traits globally by the private sector. Alternatively, can be also thought as the technology transfer costs to private/public sector
Yield difference between Bt and counterfactual (%)	Normal distribution (μ=7.8, σ=5.5; truncated at a minimum of $-\infty$ and a maximum of 51.5%)	Left hand side of the distribution truncated at $-\infty$ as a consequence of not having data regarding a potential negative difference between Bt potatoes and counterfactual (conventional varieties plus treatment.) A negative difference implies that traditional varieties have higher yields than Bt potatoes. Distribution truncated at a maximum yield loss differential of 51.5% which is the highest yield difference observed in field data collected in survey.
Storage losses (%) by using Bt potatoes versus counterfactual	Normal distribution (μ=5.9, σ=5.9, Truncated at $-\infty$ and 49%)	Truncating sampling on the left hand side of the distribution at $-\infty$ is a consequence of not having a data about the potential negative difference in storage losses between Bt potatoes and conventional varieties plus chemical treatment (i.e. possibility that Bt potatoes will not work in storage and thus farmers loose production in storage even when using Bt)

Supply elasticity (ε)	Triangular distribution (0.14, 0.92, 1.2)	A study by Ramírez Gomez et al. (2004) estimated the elasticity of supply for a series of Colombian crops. For potatoes, supply elasticities varied from 0.14 in the short run to 0.92 in the long run. We chose the values for a triangular distribution with the lowest expected value of 0.14, a most likely value of 0.92, and a maximum expected value of 1.2 which corresponds to Rao(1989) maximum value.
Cost of production differential (%) between Bt potatoes and alternative	Normal distribution (μ=8.4, σ=7.9, truncated at maximum level of 23.1%)	Mean and Standard Deviation of results from cost focus groups conducted in 2003 and 2004. Truncation at maximum level found in these focus groups.
Maximum level of adoption	35% and 95%	35% pessimistic and 95% optimistic rates of adoption
Real discount rate	10%	
Period of simulation	25 years	
R&D and regulatory time lag	7 years	Expected 4 years of contained and confined field trials, and 3 years of conventional (extended) field testing.
Adoption profile	Years	Time to maximum level=5, Time at maximum level=7, Time to dis-adopt=5
Adoption curve	Sigmoid	
Price- potato	US$ 88.6 /ton	Weighted average producer price from Table 2 over all classes & tuber sizes.

The software program randomly generates a sample value from the proposed distribution and calculates values for pre-established output variables. We collected information on output values for producer surplus, net present value and internal rate of return. We allowed the software program to generate 50,000 iterations for each scenario. In the design of the simulation worksheets we estimated producer surplus and net benefits on a yearly basis for the total number of years of the simulation. Based on the stream of yearly estimates we calculated the Net Present Value (NPV) and Internal Rate of Return (IRR) to society. Each scenario will be discussed in detail below, however it is worthwhile to discuss those variables where we substituted a static value for a probability distribution.

Elasticities. We utilized a triangular distribution for the elasticity of supply. The minimum value for the distribution is 0.14, the most likely is 0.92 and the maximum value is 1.2. These values where chosen based on estimates in the literature, particularly from an econometric study done in Colombia.

Field and storage losses. For the distribution of field and storage losses, we used the expected loss values in Figure 4 to estimate the parameters characterizing a normal distribution. Thus, we estimated the mean and standard deviation over available years for IPM managed systems for both yield and storage losses. Then we combined yield and storage losses into a joint production loss value. We used the Normal distribution (μ=7.8, σ=5.5) for yield losses truncated at a maximum value of 18.4 percent (the maximum value of all years in our survey). We left open the minimum value for yield losses at $-\infty$. The $-\infty$ yield difference assumption implies that there is no pest pressure from the GTM and/or that the Bt variety yields less than its counterfactual of a conventional variety managed in a conventional system. In contrast the maximum yield loss of 18.4 percent is the maximum recorded point estimate in our calculations of expected losses for either IPM or conventionally managed system. In the case of storage losses we also utilized a Normal distribution (μ=5.9, σ=5.9) truncated at a maximum value of 15.7 percent, which is the highest expected storage value for either IPM or conventionally managed system collected from farmers in our study. We left open the negative tail of the storage losses distribution at a minimum value of $-\infty$. For yield and storage differences, the assumption of having a left hand value of $-\infty$, is tempered by the shape of the normal curve which tends to be flatter at both tails. Therefore, the probability of the computer software sampling negative values using this distribution is actually small.[23]

Cost differences. To describe the cost difference for controlling the target pest between Bt potatoes and the counterfactual (conventional varieties managed traditionally), we utilized a Normal distribution with μ=8.4, σ=7.9. The cost difference estimated here does not include the fee or premium for use of the technology. Data for the distributions was collected from the CORPOICA-IFPRI focus groups that examined the costs of production between varieties managed conventionally and those in an IPM managed systems. We assumed that a *Bt* variety

[23] We also recognize that Bt potato technology may not be 100% efficient in controlling GTM populations in the field. Experience in the field with all Bt crops has demonstrated that effectiveness may vary from 80% to 100% population reduction. As the relationship between population levels and damage is not linear, therefore this calls for utilization of damage/biophysical models that take into consideration population levels, survival rates, ingestion of plant tissue such as the ones proposed by Linacre and Thompson (2005)

would be able to reduce the cost of pesticides and labor utilized to control the tuber moth. The possibility exists that the cost of control of the counterfactual is actually less than that for the *Bt* varieties (i.e. the cost difference is negative). As we do not have better data, we allow the distribution to take the possible values based only on mean and standard deviation.

Due to the uncertainty surrounding costs, for three of the simulations we imputed an additional distribution for the cost of adaptive R&D and compliance with biosafety regulations based on values reported in different publications.,. For the cost of regulation we used a triangular distribution with a value of $600,000 as the minimum expected value, $980,000 as the most likely value, and $2,000,000 as the highest expected value for the course of the development phase. The mean value for the cost distribution is US$1,193,000. These costs are distributed equally over the assumed 7 year time lag for R&D and biosafety compliance. They are also transformed to present values in our estimations. Estimating a value for the cost of adaptive R&D and/or biosafety regulations is challenging. However, the purpose of including the value of the cost of regulation is to examine the consequences of having a degree of uncertainty about the likely costs of technology transfer to producers, before making an investment in the technology. Costs considered here are the R&D and technology transfer costs incurred by a private or public sector investor who desires to move the technology from the lab to a field in Colombia. They do not include post-release monitoring and other activities (such as crop management registration and certification of good segregation).[24] All of these costs may or may not be recovered in the technology fee or premium charged to farmers.

Varietal choice and adoption levels. Finally, one of the critical assumptions regarding impact is the variety chosen by innovators for inserting the *Bt* gene technology. Based on the

[24] One of the readers of a draft of this paper pointed out this very significant issue which was not clearly explained in the text. We wholeheartedly agree and expect to include post-release costs when we obtain good estimates of such, as well as make additional estimates for specific questions relevant to investors.

experience with *Bt* potatoes in the USA, and from conversations with large potato processors in Colombia, there appears to be increasing resistance to the use of GM technologies destined for industrial uses or processing (e.g. , the French fries market in Colombia). Taking this issue into consideration, perhaps the most likely target variety for the inclusion of the *Bt* gene is Parda Pastusa. As this variety constitutes roughly 50 percent of the area planted in Colombia, we assumed that the maximum potential area for adoption of the *Bt* potato is the total area planted to Parda Pastusa, and thus the maximum adoption level is the current adoption level of Parda Pastusa. This assumption is very artificial as it does not consider adoption dynamics and changes in preferences of farmers moving from industrial varieties to a Bt Parda Pastusa variety and it is a fairly conservative assumption. We further assumed that for the maximum effective adoption level, farmers would have two separate rates of adoption (of the maximum potential area) for the *Bt* potato variety: 35 and 95 percent of the maximum potential area for a pessimistic and optimistic estimate respectively.

Simulation results

Results of the different scenarios are presented in Table 12.

Table 12--Smulation results

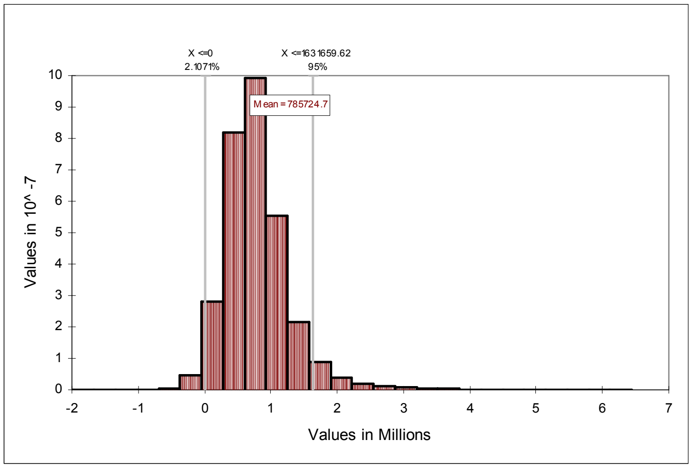
	Scenario 1 Ventaquemada region only	Scenario 2 Ventaquemada region only	Scenario 3 Boyacá + Cundinamarca	Scenario 5 Boyacá + Cundinamarca
Total hectares planted to potatoes	3,062	3,062	97,000	97,000
Maximum hectares assuming insertion in Parda Pastusa	1,531	1,531	48,500	48,500
Maximum adoption level (%)	35	95	35	95
Effective hectares adopting Bt potatoes	536	1,454	16,975	46,075
Technology fee (or technology transfer cost) per hectare	0	$ 80	$80	$20
Average cost of R&D and	0	1.1 million US$	1.1 million US$	1.1 million US$

Technology transfer Net present value (NPV) of Producer Surplus				
Mean, (US$)	785,725 *(138,287; 1,631,660)*	1,333,345 (-575,356; 3,819,739)	20,213,700 (-420,235; 47,261,590)	67,608,640 (8538877; 145,189,800)
Standard Deviation	494,486	*1,445,622*	15,678,180	45,049,340
Minimum; Maximum	(1,987,476); 6,437,598	*-3,791,295; 15,373,910*	-62,959,400; 186,599,900	-99,423,330; 581,229,900
Internal Rate of Return (%)	*Not applicable*	*20.18%*	53.8%	76.9%

Notes:
1) We used @Risk™ to run 50,000 iterations per Scenario. Convergence to a mean value was monitored and was reached when values < 1.5%. All results converged for both NPV and IRR output values.
2) Maximum hectares are estimated as 50% of total hectares as we assume the Bt gene will be inserted in Parda Pastusa only.
3) Number in parentheses for NPV are the 5% and 95% percentile values. As per Davis and Espinoza (1998) this constitutes the confidence interval.

Scenario 1 considers the alternative where the *Bt* potato will be deployed only in the Ventaquemada region of Colombia. The total area planted with potatoes in the region is roughly 3,062 hectares, and the maximum adoption area for the Bt potato being 1,531 hectares to accommodate insertion of the Bt gene into Parda Pastusa only. This scenario does not consider any type of R&D or technology transfer costs, or any recovery of such costs through a technology premium. In essence, this is a scenario that reflects pure price effect of yield gains and cost reductions. The Net Present Value (NPV) of net benefits to producers is $785,725 over the 25 years of the simulation. Furthermore as can be seen in Figure 5, there is a 2.1 percent probability that the NPV will be negative. This scenario is used mostly to calibrate the model and establish a baseline to compare our following results.

Figure 5-- NPV distribution for Scenario 1



It is not feasible to estimate an Internal Rate of Return (IRR)[25] as no cost is involved in the calibration. The main question that can be raised from this scenario is that if this is a "costless" technology, why are there negative results? The answer lies in the price effect caused by the adoption of the technology. The negative price effect due to the shift rightward and downward of the supply curve may be higher than the potential benefits due to yield and cost savings.

What happens when we include the cost of technology transfer and/or profits to innovators? That is, that either the public or private sector establish a technology fee or premium for using the technology. The technology fee can be thought of as the opportunity cost of providing technology transfer services if the technology is developed by a public sector institution. We explore the consequences of having two distinct levels of technology fees - US$20 and $80 per hectare- in Scenarios 2, 3 and 4[26]. This is the range of technology fees reported in the literature for crops incorporating the *Bt* gene.

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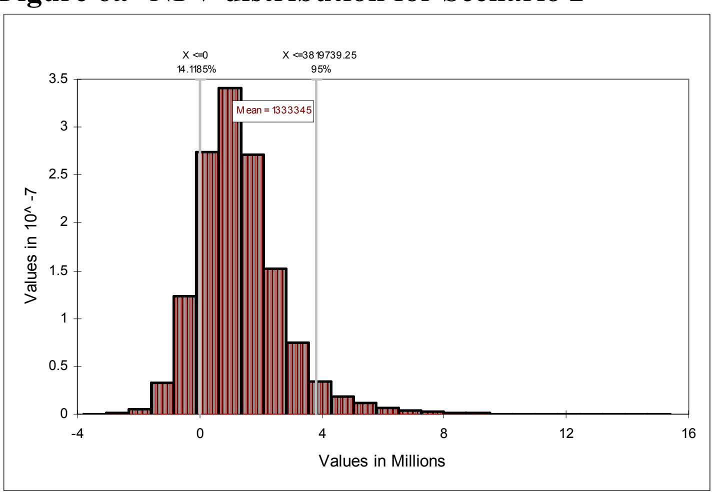
[25] We also collected information on the distribution of the Internal Rate of Return output. As these results do not show any particular inconsistency, they are not included, but are available from the authors.
[26] See Falck-Zepeda et al 2000; Huang et al. 2002; Bennett et al. 2004; for Bt cotton. In the USA, the average technology fee paid for the Bt potato (NewLeaf™) was between $49 and $72 dollars per hectare (Carpenter and Gianessi; 2001).

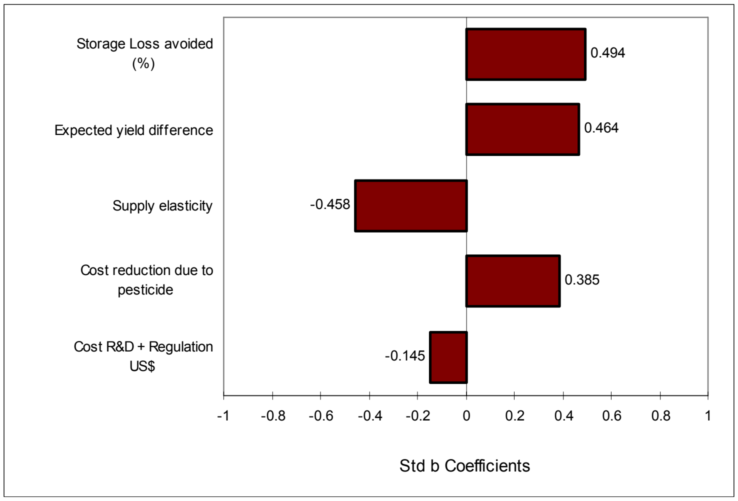
In Scenario 2, we increased the maximum adoption level to 95 percent but also considered a technology fee of $80 per hectare and a 1.1 million US$ investment in R&D and/or technology transfer activities. The adoption level increase extends the potential area where adoption may occur to encompass both departments of Boyacá and Cundinamarca with a total area 1,454 hectares. This scenario is somewhat more realistic than Scenario 1 as it considers cost to both the producer and the innovator from using the technology. However, the estimations here are returns to society and thus, from the standpoint of R&D institution, this scenario does not answer the critical question of the target area necessary to recuperate investments costs. In Scenario 2 of Table 12, results from our simulations indicate that the NPV of the stream of net benefits to farmers is $1.33 million US$ with an IRR of 20.2 percent. This result is as expected, when area is increased benefits to society also increase. In addition, as seen in Figure 6a, the probability of NPV being negative over the life of the project is roughly 14.2 percent.

Figure 6a--NPV distribution for Scenario 2



How sensitive are the NPV results to changes in inputs[27] such as yield and storage losses? To find out an answer to this question we used the @Risk™ program to measure the sensitivity of the NPV to changes in inputs. Results from this regression are presented in Figure 6b.

Figure 6b--Tornado graph illustrating regression sensitivity in Scenario 2



These results show that both yield and storage losses are the highest valued inputs in terms of affecting the NPV while using the *Bt* technology. In both cases the *b* coefficient indicates that a 1 percent increase in value increases NPV by 0.5 percent. The result for cost reductions may seem counterintuitive. For every 1 percent reduction in the use of pesticides achieved through the use of *Bt* potatoes, NPV increases by 0.38 percent.

Scenario 3 in Table 12 presents the result of expanding the maximum area to Boyacá and Cundimarca but allowing the maximum adoption rate to be 35 percent. This assumption is equivalent to having a total area planted to potatoes of 97,000 hectares, maximum target area of 48,500 hectares, and a maximum potential adoption of Bt potatoes of 16,975 hectares. In this scenario, NPV increases to roughly 20.2 million dollars over the 25 years of the simulation with

[27] Here we use the @Risk terminology, where the distributions used for sampling, constitute "input" to the simulation. In turn, the outputs of the simulation are the results of changing input values, in our case the NPV or the IRR.

an IRR of 53.8 percent. Figure 7a shows the distribution of NPV for Scenario 3. The mean value of the NPV for this scenario increases with respect to previous scenarios. It is interesting to note that the probability that the NPV will be negative decreases to 5.4 percent. This is almost half the value for Scenario 2. Results from the Tornado graph in Figure 7b are quantitatively similar to results from previous scenario.

Figure 7a-- NPV distribution for Scenario 3

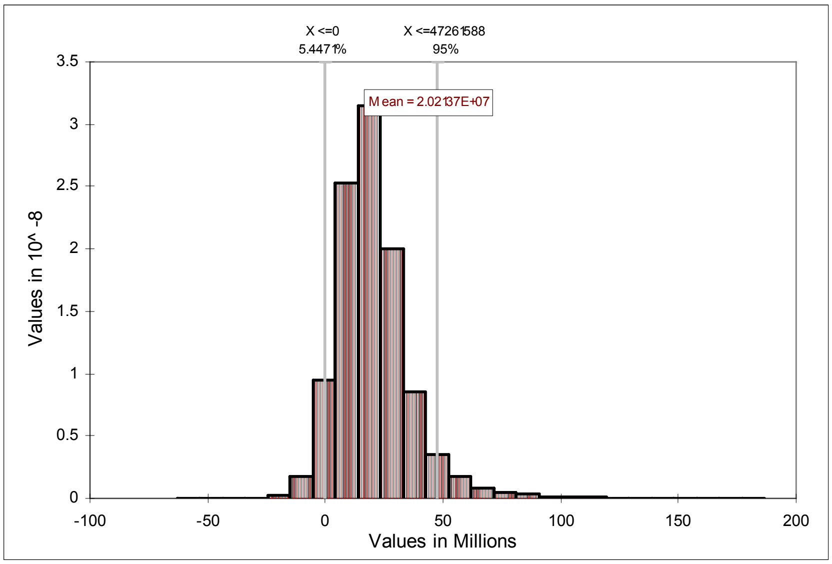


Figure 7b Tornado graph illustrating regression sensitivity of Scenario 3

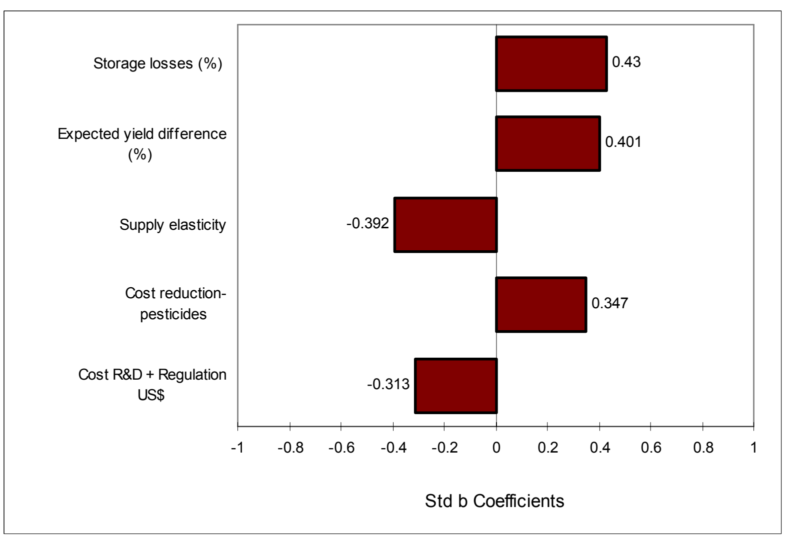
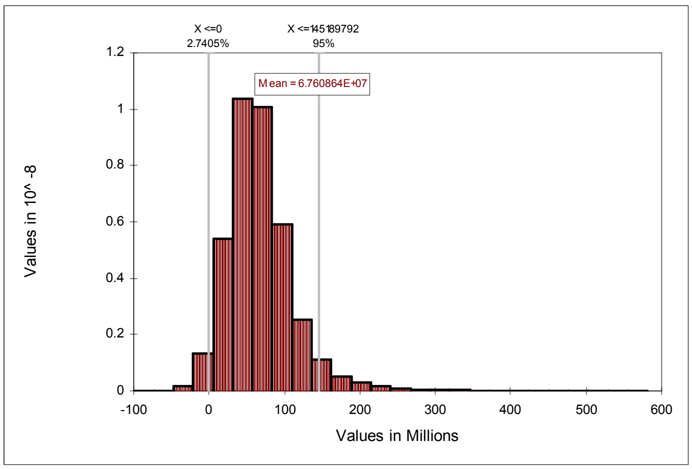


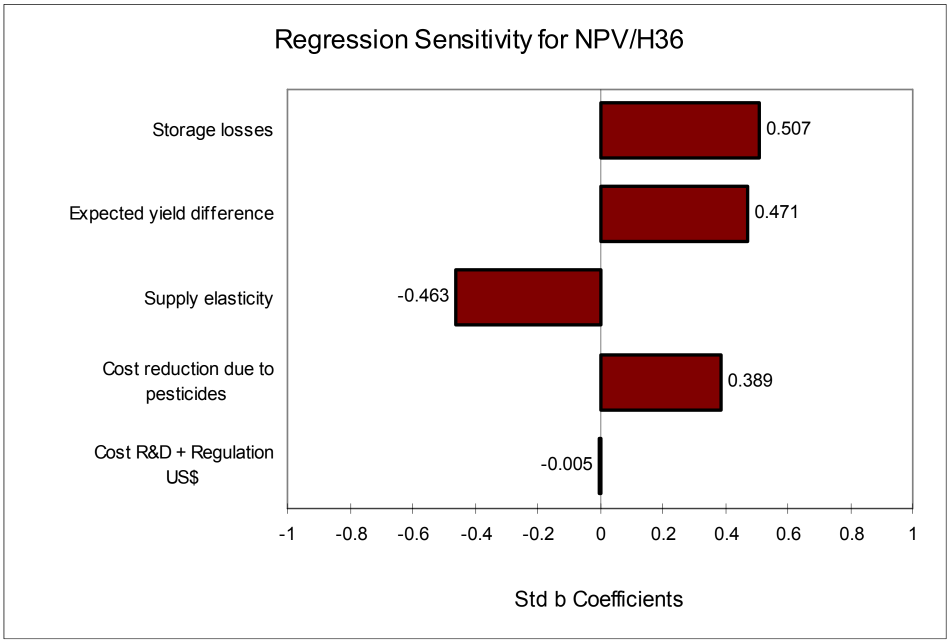
Table 12 present results from Scenario 4. In this scenario we increased the maximum adoption rate to 95 percent, and reduced the technology fee to the lower level of US$20 per hectare. , Adopting *Bt* potatoes increases the NPV to $67.6 million dollars and the IRR to 76.9 percent, as compared to Scenario 3. The probability of the NPV being negative also decreases with respect to other scenarios to 2.74 percent (See Figure 8a).

Figure 8a--NPV distribution for scenario 4



Results for input sensitivity in Figure 8b are similar to other scenarios thus lending some support to the robustness of these estimates and their relative value with regard to input effect on output values.

Figure 8b--Tornado graph illustrating regression sensitivity of Scenario 4



When we compare the results of all scenarios we can start observing the size /scale effect of investments in plant breeding and biotechnology. That is, given a fixed cost of development, the larger the maximum target area, the higher the returns to investment. In terms of biotechnology innovations, we will have to modify our results (in future papers) in terms of whether each individual gene insertion will require a full biosafety assessment versus the notion that once the technology is available, we can in fact introduce the technology to any set of varieties, provided one pays the royalty fees requested.

Our results show that inputs to the model such as yield and storage losses have a critical effect on the NPV of benefits obtained by farmers. We extended our analysis to obtain more detail on how sensitive our results are to input values. This process also served to test the robustness of our results to a certain degree. We ran the advanced sensitivity analysis option in @Risk to examine this issue. Results of the advanced sensitivity analysis are presented in Table 13 and Figure 9.

Table 13--Advanced sensitivity analysis of NPV response to changes in inputs in Scenario 4

Inputs Ranked by Mean			Output			
Name	Analysis	Value	Mean	Min	Max	Standard Deviation
Expected storage losses	Base +10.00%	8.946666527	$218,045,561	($25,837,250)	$526,180,122,624	$3,244,630,939
Expected yield loss	Base +10.00%	8.616666842	$215,571,164	($25,587,226)	$526,333,640,704	$3,098,652,261
Expected storage losses	Base +6.67%	8.67555542	$214,643,401	($25,969,474)	$518,486,523,904	$3,195,548,843
Expected yield loss	Base +6.67%	8.355555725	$212,298,948	($25,701,256)	$518,923,288,576	$3,051,850,832
Expected storage losses	Base +3.33%	8.404444313	$211,247,874	($26,152,526)	$510,807,474,176	$3,146,569,014
Expected yield loss	Base +3.33%	8.094444609	$209,032,884	($25,814,674)	$511,526,404,096	$3,005,149,666
Expected storage losses	Base +0.00%	8.133333206	$207,858,980	($26,334,944)	$503,142,940,672	$3,097,691,814
Expected yield loss	Base +0.00%	7.833333492	$205,772,975	($25,927,476)	$504,143,020,032	$2,958,549,523
Expected storage losses	Base - 3.33%	7.862222099	$204,476,719	($26,516,724)	$495,492,923,392	$3,048,917,556
Expected yield loss	Base - 3.33%	7.572222376	$202,519,218	($26,039,656)	$496,773,103,616	$2,912,050,839

Figure 9-- Mean of NPV vs. percentage change of inputs for scenario 4

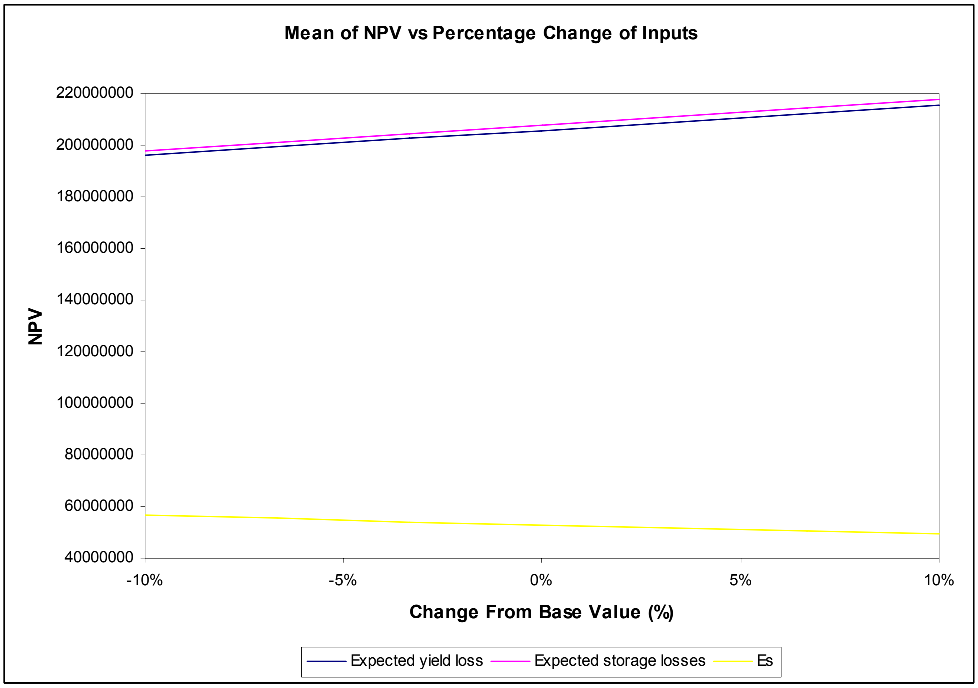


Table 13 summarizes changes to the simulated distribution for NPV caused by "stepping" through 3 inputs (yield losses, storage losses and supply elasticity). Each input is "stepped" through seven values, and a full simulation was run at each value. A total of 21 simulations (50,000 iterations per simulation) were completed at the end of the run. We can see from Figure 9 and Table 13 that results are fairly robust to changes in the +/- 5 and 10 percent changes in value. These results indicate that the input sensitivities estimated in all the different scenarios through the *b* coefficient in Tornado graphs are fairly good estimates of their true value and thus may be used as an indicator of their true contributing value.

5. DISCUSSION

Our results have interesting applications for the national agricultural research organizations in Colombia, in particular for those whose mission is to supply appropriate technologies and to help farmers overcome their production constraints. Our results show that IPM managed systems continue to have a role in potato production in Colombia. Questions remain about the availability of some of the components of the IPM portfolio in Colombia, as well as understanding their relative value to producers. Our results also show that *Bt* potatoes may be a viable strategy to the management of the Guatemala Tuber Moth complex, particularly for those situations where heavy damage is present. In addition, IPM and the use of Bt potatoes may be complementary as there is still the need to manage secondary pests not controlled by the *Bt* technology. Further research to study and define IPM portfolios that incorporate *Bt* potatoes as an integral part of the interventions available to manage *Bt* technologies may be warranted. However, as mentioned above, there are many indications that precipitation has a very significant causal role in determining pest levels and thus damage in subsequent crop cycles. Therefore, in the absence of other considerations, one potential (stylized) management strategy for farmers would be to utilize the *Bt* technology after a series of dry periods and in turn carefully assess the value of the technology after 1 or 2 cropping cycles of precipitation. Of course, this strategy falls apart when one considers that germplasm enhancement and maintenance in potatoes is a long-term activity. In addition, there are questions about technology transfer in terms of who will do the transfer, and who will provide the knowledge necessary to manage the crop within a traditional and/or IPM managed system. After considering these realities, another aspect that requires further analysis is the insurance value of the *Bt* technology (and to a degree IPM as well) and problems related to producer vulnerability.

We found in our study that by including a given level of R&D and biosafety regulatory compliance costs and time lag, net economic benefits to society are reduced. This is a consequence of delaying the onset of the stream of benefits necessary to release the technology to farmers. This statement needs to be qualified as the analysis does not consider the potential gains to society in terms of the knowledge, information and safety acquired during the R&D and biosafety process.

An expected result of the inclusion of a fixed level of R&D and biosafety costs necessary to develop a GM technology decreases net benefits to society and to innovators others things kept equal. We can also see different scenarios where, for example, those GM technologies that have to be developed and go through biosafety regulatory approval process, innovators need to amortize costs over a larger area to justify investments. In contrast, if there is an existing technology that has already gone through the adaptive R&D and biosafety processes (i.e. the biosafety system allows a reduced application for approved events) , the decision making process is different as the relevant costs to compare the stream of benefits are the royalty and fees necessary to use the technology.

6. LIMITATIONS AND CAVEATS

The limitations of the economic surplus model are well known in the literature (Alston, Norton, and Pardey 1995). The limitations of the economic surplus model pertaining to this study, includes the use of linear demand and supply curves, horizontal shifts of the supply curve. and the assumption of the use of a competitive market assumption; are well known. However Alston, Norton and Pardey (1995); also point out that the economic surplus model is a widely used methodology globally. Alternative methodologies and assumptions have their own set of problems and limitations. Though economic surplus model have limitations, it continues to be the best alternative for estimating benefits to R&D processes. One of the major limitations of our study is the inherent dynamic nature of pest infestations and their response to environmental situations. We provide a partial solution to this problem by using "expected" yield estimates with some risk considerations and dynamics.

One important aspect for R&D institutions considering developing GM potatoes is that consumers in Colombia attach a significant weight to variety attributes. Different varieties in Colombia have specific end uses. Consumer preferences for varieties with specific attributes can be summarized by what the phrases "I am finicky about my potatoes" or "Don't touch my potatoes." Consumer perceptions that a genetic modification can alter these attributes may be strong enough, and be transferred along the marketing chain, that it may affect demand for a variety developed with a GM trait. This implies that R&D institutions have to develop communication strategies to inform consumers about the cost, benefits and safety of the product, as well as about any potential changes in the attribute mix of the transgenic varieties.

Finally, our results are challenged by the reality that Guatemalan Tuber Moth attacks have not been high during the first two years of the study. Preliminary examination of the third year of data collection seems to tell the same story. Therefore our knowledge about the dynamics of GTM damage and thus of the potential value of IPM and genetic modifications continues to be incomplete. We will strive to close this knowledge gap over time.

7. SUMMARY AND CONCLUSIONS

The analysis of impact of the adoption of IPM practices destined to manage the Guatemalan Tuber Moth (*Tecia solanivora* Povolny) has three important characteristics that differentiate it from other technologies. First, adoption of IPM portfolios is characterized by partial or stage adoption of components of the portfolio. This pattern of adoption may affect the overall effectiveness of preventive measures. Second, pest management is not a conventional input that behaves as others, with a standard marginal revenue curve. Rather, we are dealing with damage control; therefore the production function is bounded by intrinsic productivity of the plant, its interaction with the environment and the management done by the producer. This implies that the sources of adoption profitability are less use of chemical pesticides and a reduced loss of production. Finally, the Tuber Moth depends to a large degree to climate, in particular precipitation. The survey we conducted coincided with a year of a food distribution of precipitation. This in turn implied low pest attack and low damage. In contrast, IPM practices are of a preventive nature and therefore have to be done, before the pest attack.

We applied a conventional partial budgeting analysis (incremental costs/incremental benefits) that showed that the use of IPM practices was profitable for farmers during the second semester of 2003. Yet, the use of IPM practices was not profitable for the first semester of 2004, because the reduction of the use of pesticides was low, not only on conventional but also for the IPM system. In both cases, producers reported low attack by the Guatemalan Tuber Moth, and thus there was no significant effect on production. This analysis has a geographical and time context and is limited as it is a snapshot of the period production environment. Furthermore, the snapshot taken during our study was done in a period of very low infestation and damage by the target pest. We can only draw very limited conclusions, as basing conclusions exclusively on the snapshot taken does not reflect the dynamics and temporality of the pest.

In order to obtain a much more dynamic vision of the production environment faced by Colombian producers in the region, we compiled actual an historical data on damage reported by farmers interviewed. These damages can be an over estimation, as producers in the area tend to magnify the level of damage. However, they may as well be an under estimation, as we asked farmers about the three crop cycles with the largest damage, not the damage per crop cycle. The data collected and the analysis done in this paper we obtain a much more dynamic view of losses caused by the pest, and thus allow us to discriminate between damage suffered by producers that utilize an IPM system versus those that utilize the conventional system. Our analysis show that producers act rationally while utilizing IPM practices even in the case of lower levels of GTM attack, as the expected benefit is larger that the cost of preventive measures.

Result from the preliminary estimates of the ex ante assessment of economic surplus creation due to the potential use of the Bt potato technology seem to indicate a good potential to manage the pest, even in the case of uncertainty. Our results considering different levels of investments in R&D and technology transfer costs, as well as technology fees and premiums, indicate that at the technology fee levels considered in our analysis, innovators or investors may be able to recuperate their investment and at the same time deliver a technology that is useful to manage the Guatemalan Tuber Moth in Colombia, particularly when the level of infestation and damage are high. This opens a neglected area to conduct future research of examining the insurance value of *Bt* technologies. In essence, this line of discussion seeks to estimate the maximum premium payable by farmers to be able to use the technology in order to manage risk. This discussion will have repercussions in terms of funding mechanisms, strategic alliances, and the possibility of the technology becoming an integral part of the portfolio of techniques used to manage pests in developing countries.

It is recommended to continue the study in order to follow up the crop cycle and continue measuring storage losses. It is also recommended to continue collecting data on the costs of production, particularly under the farmer school launched under this project. Only a larger temporal coverage of the production cycle can allow us to quantify the true effect of IPM and the potential benefit of *Bt* potatoes in the field.

Finally, we would be remiss if we did not discuss in this paper three lines of argument with regard to the use of *Bt* technologies in potato. A distinct set of papers have shown the benefit from Bt crops in general in decreasing pesticide use (Traxler 2005; Traxler et al. 2004;

Falck-Zepeda et al 2000; Huang et al. 2002; Bennett et al. 2004). Reduction in terms of total pesticide load and the type of active ingredients used will certainly have an effect on human and animal health, and the environment. A second line of argument that is worthwhile to pursue in future papers is the intake and sustainability of the *Bt* technologies over time. Genetic modifications may have an easier intake on the part of farmers as there are is very little change in terms of management changes with regard to the crop. In addition, as our experience in Colombia has shown, farmers are not as dependent on other external inputs such as conventional pesticides, traps or pheromones required under IPM managed systems. Finally, for Colombian organizations either funding R&D in GM biotechnologies or dedicated to transferring technologies to farmers, there is a lot to do in terms of gaining the confidence of consumers and educating everybody on the assessment of risk, its analysis, and posterior safe use of the technology. Only time will tell if this paper contribute to initiate the discussion of all of these issues.

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